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A METHODOLOGY FOR THE EVALUATION OF RUNWAY ROUGHNESS FOR REPAIR

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FOREWORD

This project was accomplished through the efforts of the Structural Integrity Branch of the Structures Division, Flight Dynamics Directorate, Wright Laboratory, Wright-Patterson Air Force Base, Ohio. The work was performed under Project 24010701, "Structural Loads Predictions."

This work was performed by Mr John T. Riechers of the Loads & Criteria Group during the period of July 1990 to January 1991. The manuscript was released by the author in March 1991 for publication as a WL Technical Memorandum.

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This Technical Memorandum has been reviewed and approved.

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ABSTRACT

The Structural Integrity Branch has supported the evaluation of aircraft response to ground induced loadings through modeling since the 1970s. This report presents a methodology for the use of these modeling techniques to evaluate a runway for roughness, and rate the prospective repairs by effectiveness. This information can be used by local civil engineering to determine the extent of repairs required, and if these repairs can be accomplished under general maintenance funds allocations, or if a major construction request is necessary. This report is intended to publicize a unique capibility of the Flight Dynamics Directorate of the Wright Laboratories.

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I INTRODUCTION

Aircraft respond to roughness on a runway during taxi, takeoff, and landing in much the same way as a car to variations in the road surface. This response can be anywhere from unnoticeable to catastrophic, depending upon the amplitude and frequency of the roughness, and the characteristics of the particular aircraft. Somewhere within the response spectrum is the acceptable level for humans and their machinery. Discomfort and/or a catastrophe will occur when this acceptable level is exceeded.

During the mid 50s to mid 60s our country was involved in a tense cold war. The primary fear of everyone was the threat of global war involving the US and the USSR. This fear drove a massive build-up of the Defense Department. It was felt that a major war could necessitate sustained combat from bases within the States. This possibility required the development of long-range tactical and strategic bombing, interceptor, and fighter capabilities, as well as bases to support them. Towards this end, the Air Force invested heavily in the infrastructure of airfields in the States.

The push towards social reform in the late 60s and 70s, as well as the Vietnam War, sapped the ability of the military to maintain the state-side development. Emphasis was redirected to European, Asian, and Pacific areas. New scenarios relied on these areas sufficiently impeding aggression to allow reinforcements to be dispatched from the States. State-side bases were either mothballed, or had their mission drastically altered. During and after this period, minimal resources were allocated for the upkeep and upgrading of state-side bases, except as specific national pride projects necessitated. This neglect of existing infrastructure has created the situation that we are now beginning to see. More and more runways and taxiways are in need of major repair or replacement.

Today's austere resource environment necessitates the greatest return on any investment. Sufficient funds do not exist for the replacement of the infrastructure that may be required. Other alternatives need to be developed. This report presents a procedure to identify specific areas on a runway, or taxiway, that will benefit from repair. The procedure will also aid in the ranking of these repairs according to potential benefit. This ordered set of potential repairs may be accomplished on a limited budget over time. This report will also present the results of an investigation of the interaction of a demonstration runway with an aircraft.

II PROCEDURE

The general procedure for a runway roughness evaluation consists of computational modeling of an aircraft traversing the runway, and evaluation of the aircraft's predicted response to identify areas of concern. This procedure leads to a division of tasks in the areas of aircraft modeling, load limits, response evaluation, and roughness repair.

Modeling techniques for the response of an aircraft to rolling over runway roughness have been an area of research for over twenty years. For this effort, a modified version of the computer program TAXI, Reference 1, is used to simulate the response of an aircraft to runway roughness. The utility and value of TAXI are demonstrated in References 2 and 3. The major changes to TAXI are in the areas of beginning and end locations on the profile, and information stored during a velocity analysis. TAXI is modified to allow the user to specify any position, on the profile, as the start of the analysis. The ability to end the simulation before the end of the profile is also added. These changes allow a closer look at a specific area of the profile.

The version of TAXI in use is modified to do a velocity analysis of a profile. This velocity analysis consists of multiple constant speed passes over the profile, beginning at a defined velocity and incrementing by a constant, until reaching a limit. Data is stored for a hundred evenly spaced locations for each speed. This loads data forms a two-dimensional matrix on location and velocity.

Many different load limits are available. Among these are the aircraft design load limit through the landing gear, the tire bottoming load, and human acceleration comfort criteria. Reference 4 defines an acceptable level of human acceleration for comfort at 0.4 g's, or 0.4 times the acceleration of gravity. This criteria was chosen for this study because it is the most restrictive for the aircraft under consideration.

To aid in response evaluation and repair location definition, a contour plotting computer program is used to present the predicted loads over the profile length and velocity spectrum. Because of the human comfort criteria, particular interest is in loadings greater than 0.4 g's at either the pilot's station (PS), or center of gravity (CG). Runway response evaluation is further aided by the ability to model sections of the profile and increase the load position resolution. This allows close scrutinizing of repair positioning and an attempt to minimize the repair size and number of repairs.

Repairs are simulated with a computer program that connects the beginning and end locations with a straight line. The program keeps track of the amount of removed surface material and fill added in square yards. This information is useful for rating repairs that accomplish a defined goal. The program also keeps a record of the material removed or deposited at every spacing interval, to support shave depth restraints, and minimum overlay thickness constraints.

The tools previously defined can be used to define repairs to a given profile for a given aircraft in the following manner:

1. In all cases, use of the computer program TAXI implies a velocity analysis and contour plot of the results.

2. TAXI is run for the entire unrepaired profile to provide a feel for the overall roughness.

3. A TAXI analysis of the first 1500 feet of the profile is used to identify the first set of repairs.

4. These proposed repairs are simulated using the REPAIR computer program.

5. TAXI is run over the repaired 1500 foot profile to evaluate the effect of the first set of proposed repairs.

6. If the results are unacceptable, propose a new set of repairs and return to Step 3.

7. Define a new starting point as 1000 feet from the beginning of the profile.

8. Run TAXI for 1500 feet from the starting point and identify necessary repairs.

9. Add these repairs using the REPAIR program.

10. Rerun TAXI over the same profile section and evaluate the repairs effectiveness.

11. If the results are unacceptable, propose new repairs and return to Step 8.

12. Add the acceptable repairs to the repair set.

13. Add 1000 feet to the starting point and return to Step 7.

14. After evaluation of the profile as sections, rerun TAXI for the entire profile to verify the complete proposed repair set.

For bi-directional use of the runway, the repaired profile must be flipped end for end, and the process restarted from Step 1. After including the repairs necessary for runway operations in this reversed direction, the profile must again be flipped and checked through TAXI.

Takeoff and landing velocity/position envelopes are overlayed on the unrepaired profile TAXI output. Adding the identified repair positions allows the ranking of these repairs based upon the occurrence of responses within the takeoff and landing envelopes.

The following RESULTS section presents an example of the use of this process to repair a runway for a generic aircraft.

III RESULTS

This section presents the results of the interaction of a generic aircraft with a runway. The aircraft model is not intended to represent any particular airplane, and the runway profile is of unspecified origin. The results, conclusions, and recommendations are made to demonstrate the process and not intended for implementation.

Figure I is the response of an aircraft to the defined runway profile for the pilot's station (PS). All of the areas outlined on this plot exceed 0.4 g's at the PS. There are two distinct response bands identifiable in this figure. The first response band exists between about 60 feet per second (FPS) and 100 FPS. The second is around 220 to 240 FPS. The first band indicates a response to a "short", 20 to 60 foot wavelength excitation, while the second indicates a "long" 120 foot or greater. This information is helpful when locating repairs.

Figure II is a plot of the response of the center of gravity (CG) to the defined runway profile. There are no points on this profile that cause a CG response greater then 0.4 g's.

Figure III is a plot of the response of the PS to the first 1500 feet of the runway. A very clear response is indicated in the 900 to 1020 foot length. A repair is suggested between about the 820 and 1060 foot points. This repair requires the shaving of 0.031 sq. yards and a fill of 0.290 sq. yards, over a 240 foot length. This information is provided by the REPAIR computer program. The program also provides a plot of the original and repaired profile, as is shown in Figure IV.

Figure V is a plot of the PS response to the first 1500 feet of the runway with the proposed repair. The lack of any response below the 1400 foot mark is an indication of the effectiveness of the proposed repair.

Figure VI is a plot of the PS response to the 1000 to 2500 foot section of the profile. This area of the profile is to be repaired with three repairs. The first is from 1390 to 1500 feet, the second, 1700 to 1840 feet, and the third, 1960 to 2280 feet. These repairs require the shaving of 0.819 sq. yards, and fill of 0.109 sq. yards. Figure VII is a plot of the response to the repaired profile.

This procedure of modeling the response to 1500 feet of runway, repairing the profile, and checking the results is continued for the entire length of the runway. Upon completion, the entire repaired runway profile must again be checked to insure that no dynamic interactions have been missed by the breakdown of the profile. Figure VIII is a plot of the PS response to the entire repaired runway profile. Figure IX is a plot of the CG response to the repaired profile. The lack of response at either of these areas indicates that this repair set is viable for operations in this direction. This repair set includes 21 repair positions, covering 2714 feet of the runway, and requires the shaving of 3.606 sq. yards and fill of 0.916 sq. yards.

To check for operations in the reversed direction, the repaired profile must be flipped end for end, and the entire flipped repaired profile used for a velocity analysis. Figure X is the PS response to the flipped repaired profile, while

Figure XI presents the CG response. As indicated by Figure X, more repairs are necessary to allow bi-directional operations.

Figure XII gives an expanded view of the 6000 to 7500 foot range for the reversed direction. A 140 foot repair from 6788 to 6928 in this direction will correct this response. Figures XIII and XIV present the PS and CG responses to this corrected profile for reversed direction operations. Figures XV and XVI present the PS and CG responses to the corrected profile in the original direction.

The set of 22 repairs covering 2854 feet and requiring 3.606 sq. yards of shaving and 1.625 sq. yards of fill will allow complete confidence in bi-directional operations from this runway. This set of repairs, covering nearly 40% of the runway, is unacceptable to undertake as maintenance. More information is necessary to prioritize these repairs. Figure XVII presents the takeoff and landing envelopes for single direction operations. These envelopes exclude a large portion of the velocity/position space.

Figure XVIII is an overlay of the PS response to the unrepaired runway in the forward direction with the identified repair positions and the landing and takeoff envelopes. Repairs 1, 2, 10, 11, 12, 13, 14, 15, 16, and 17 all have associated responses inside of the envelopes. Repairs 3, 4, 5, 6, 7, 8, 9, 18, 19, 20, 21, and 22 are not due to responses inside of the envelopes.

Figure XIX is an overlay of the PS response to the unrepaired runway in the reversed direction with the identified repair positions and the reversed landing and takeoff envelopes.

Repairs 1, 2, 3, 4, 7, 8, 9, 11, 12, 13, 14, 15, 16, 17, and 20 all have associated responses inside of the envelopes. Repairs 5, 6, 10, 18, 19, 21, and 22 are not due to responses inside of the envelopes.

Combining the conclusions from Figures XVIII and XIX, repairs 1, 2, 11, 12, 13, 14, 15, 16, and 17 are considered high priority, because they will effect the operations envelopes for both directions of travel. Repairs 3, 4, 7, 8, 9, 10, and 20 are medium priority, because they only effect operations in one direction or the other. Repairs 5, 6, 18, 19, 21, and 22 are low priority, because they will have no effect on the normal operational envelopes in either direction.

The high priority set of repairs includes 9 repairs, covering 894 linear feet of runway, requiring 0.378 sq. yards of fill and 0.973 sq. yards of shaving.

The analysis reported in this document required approximately two weeks of work. This time is contingent upon the existence of the runway profile data and a computer program to modeling the aircraft.

IV CONCLUSIONS

1. A methodology exists to analyze the effects of runway or taxiway roughness on an aircraft.

2. This methodology can be utilized to optimize repair position and configuration.

3. This methodology can be utilized to estimate the magnitude of each proposed repair.

4. This methodology can be utilized to rank order proposed repairs according to their operational effectiveness.

5. Manhour time requirements for this work are about one hour for each one hundred feet of profile.

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APPENDIX

FIGURES

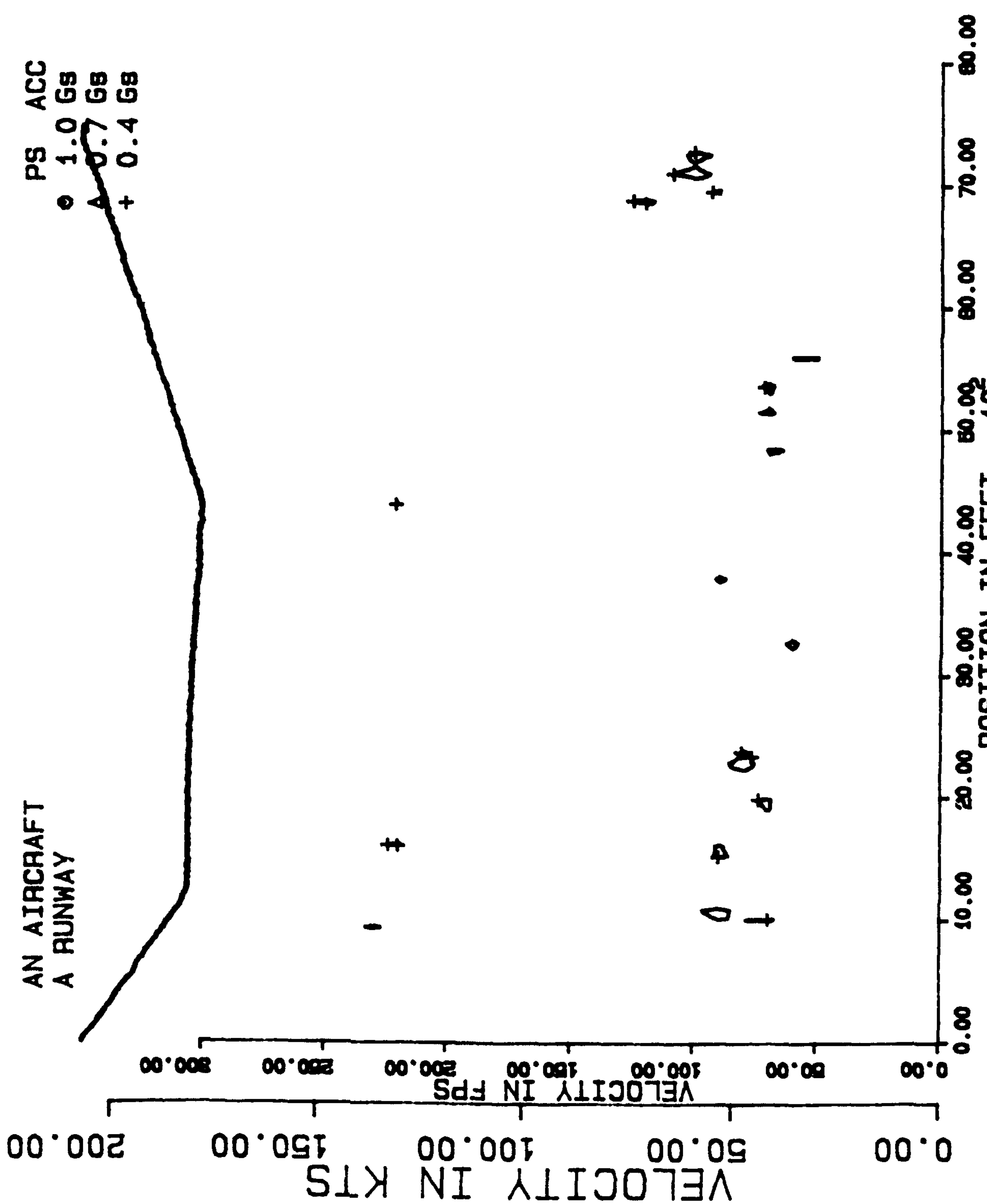

FIGURE I: PILOT'S STATION (PS) RESPONSE TO UNREPAIRED RUNWAY

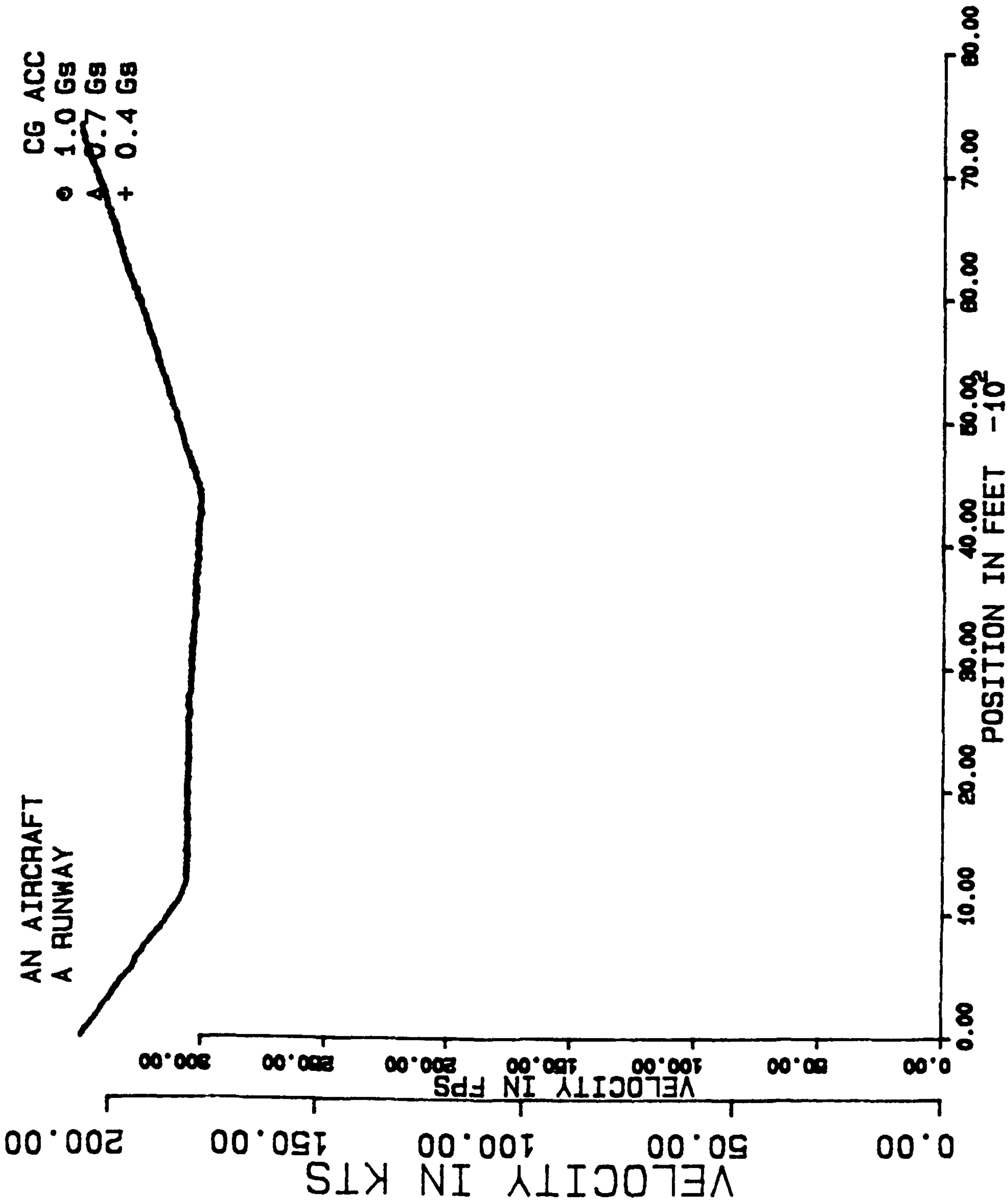

FIGURE II: CENTER OF GRAVITY (CG) RESPONSE TO UNREPAIRED RUNWAY

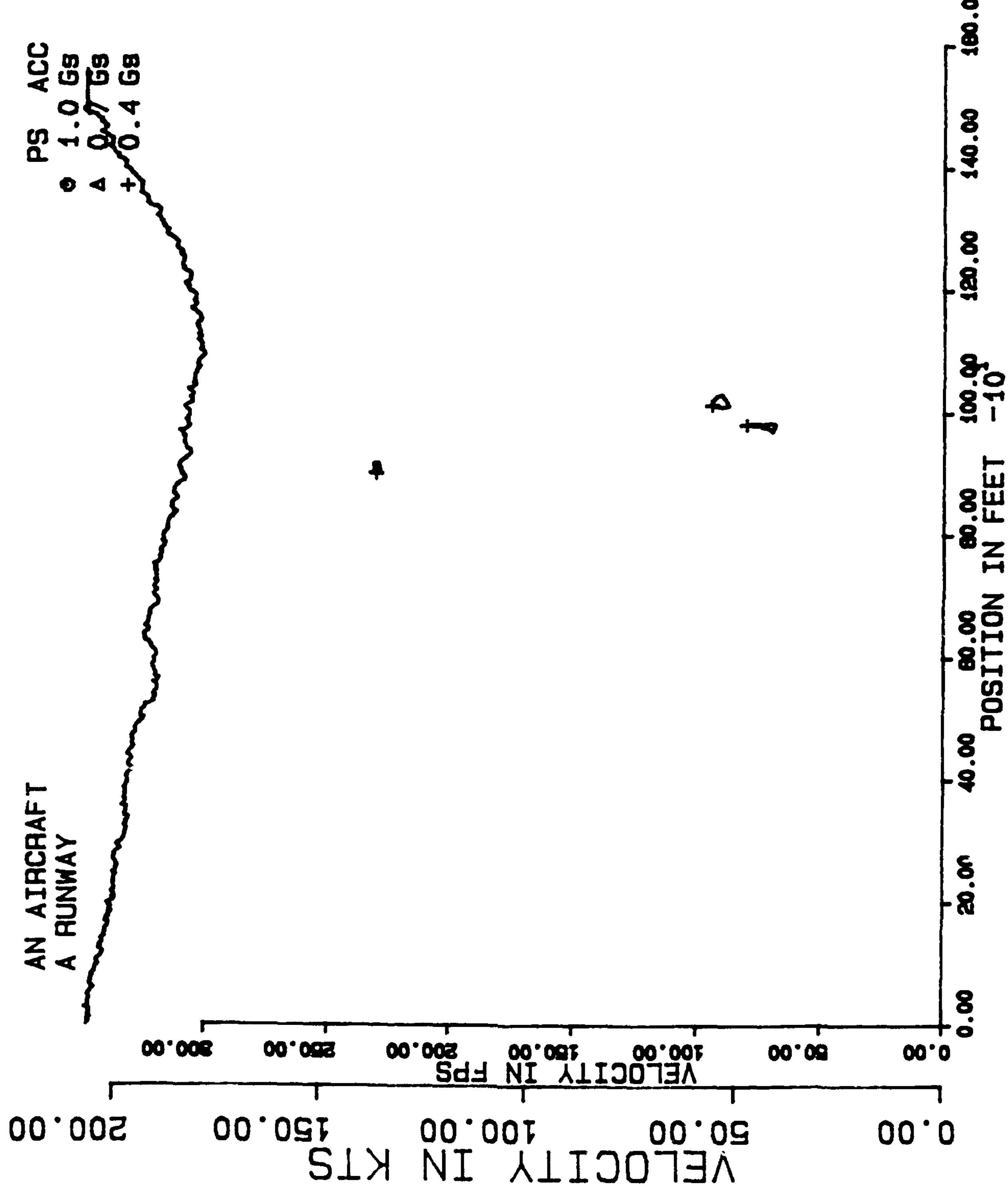

FIGURE III: PILOT'S STATION RESPONSE TO 0 TO 1500 FEET

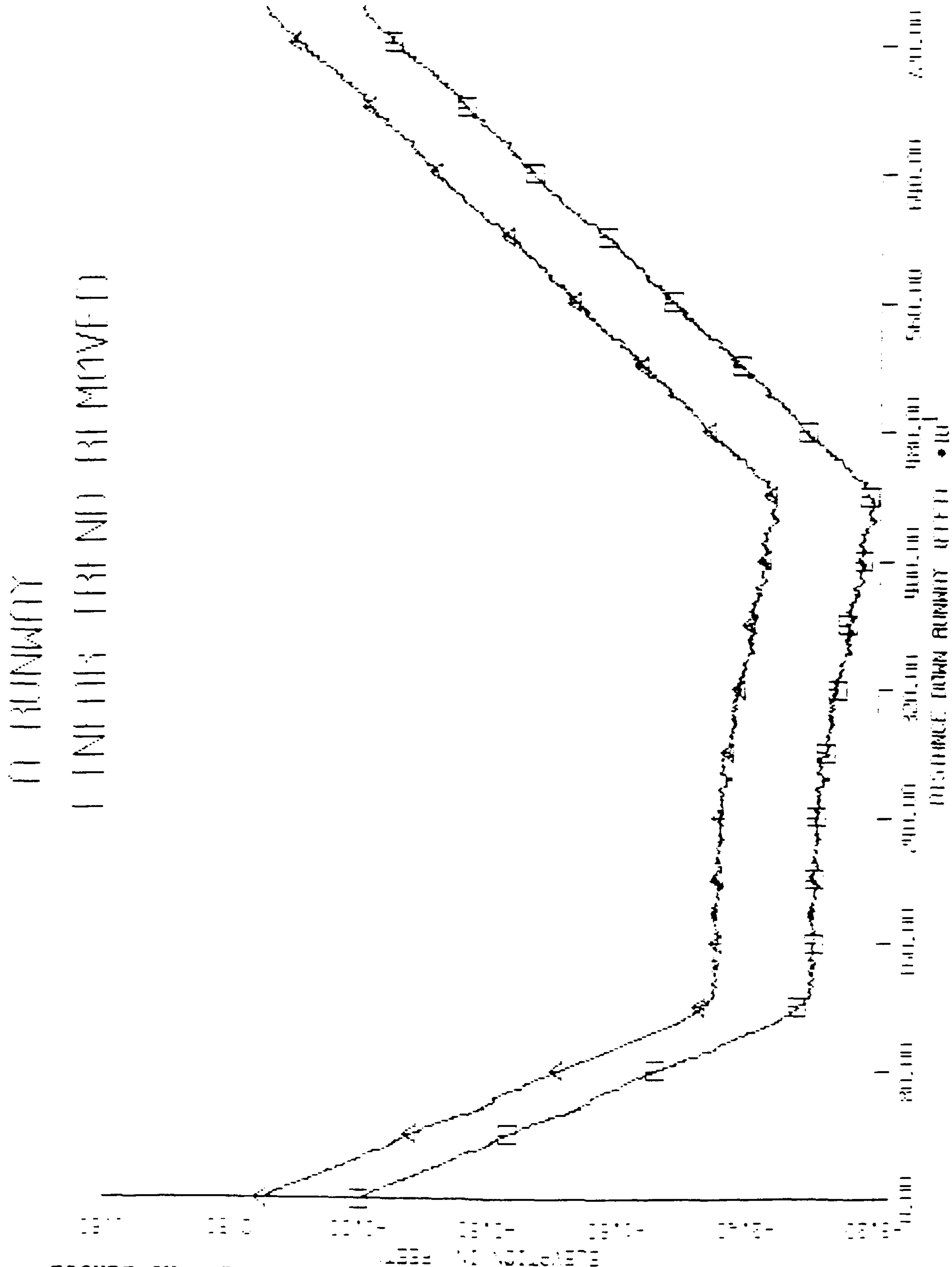

FIGURE IV: RUNWAY PROFILE BEFORE AND AFTER FIRST REPAIR

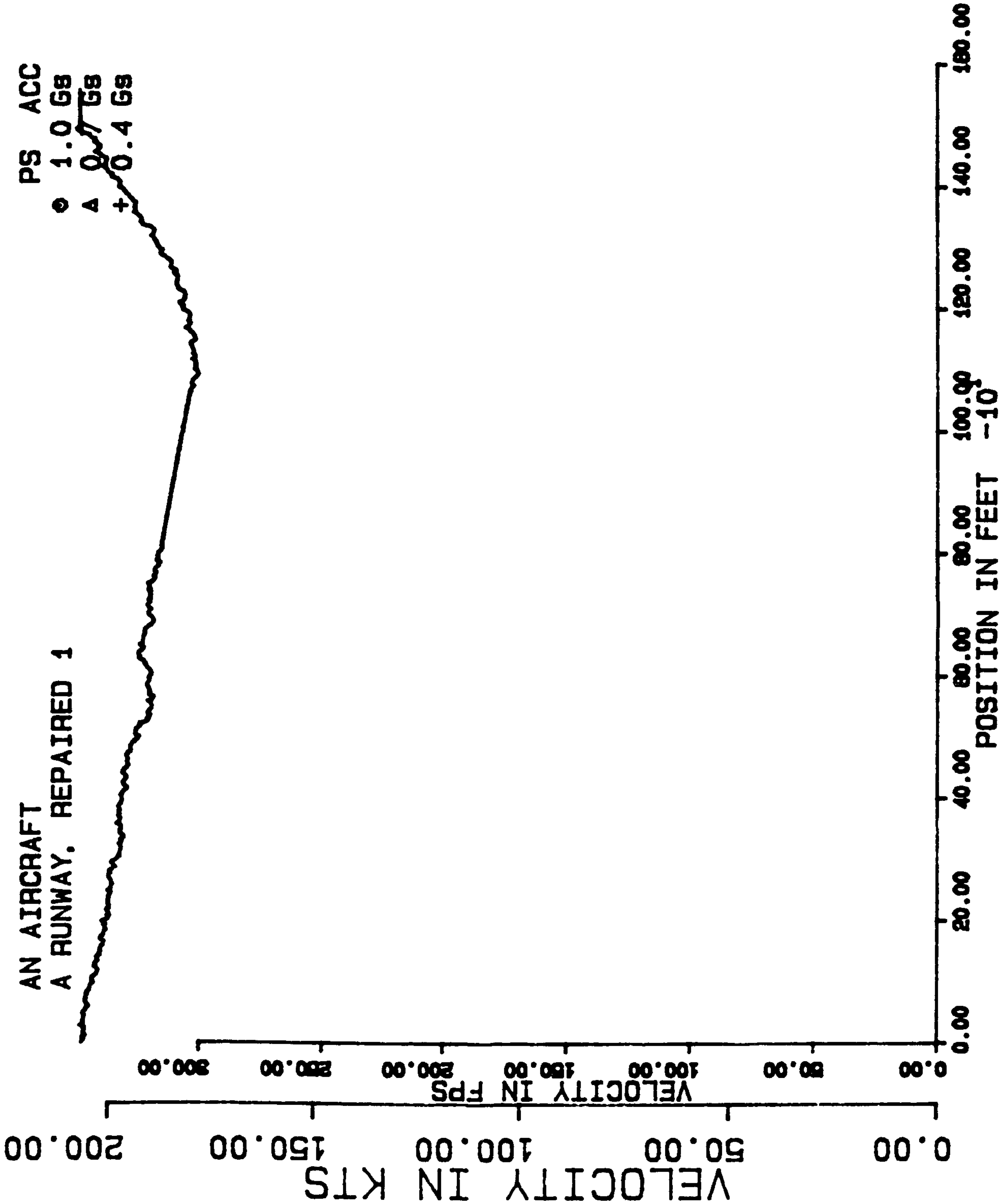

FIGURE V: PILOT'S STATION RESPONSE TO REPAIRED 0 TO 1500

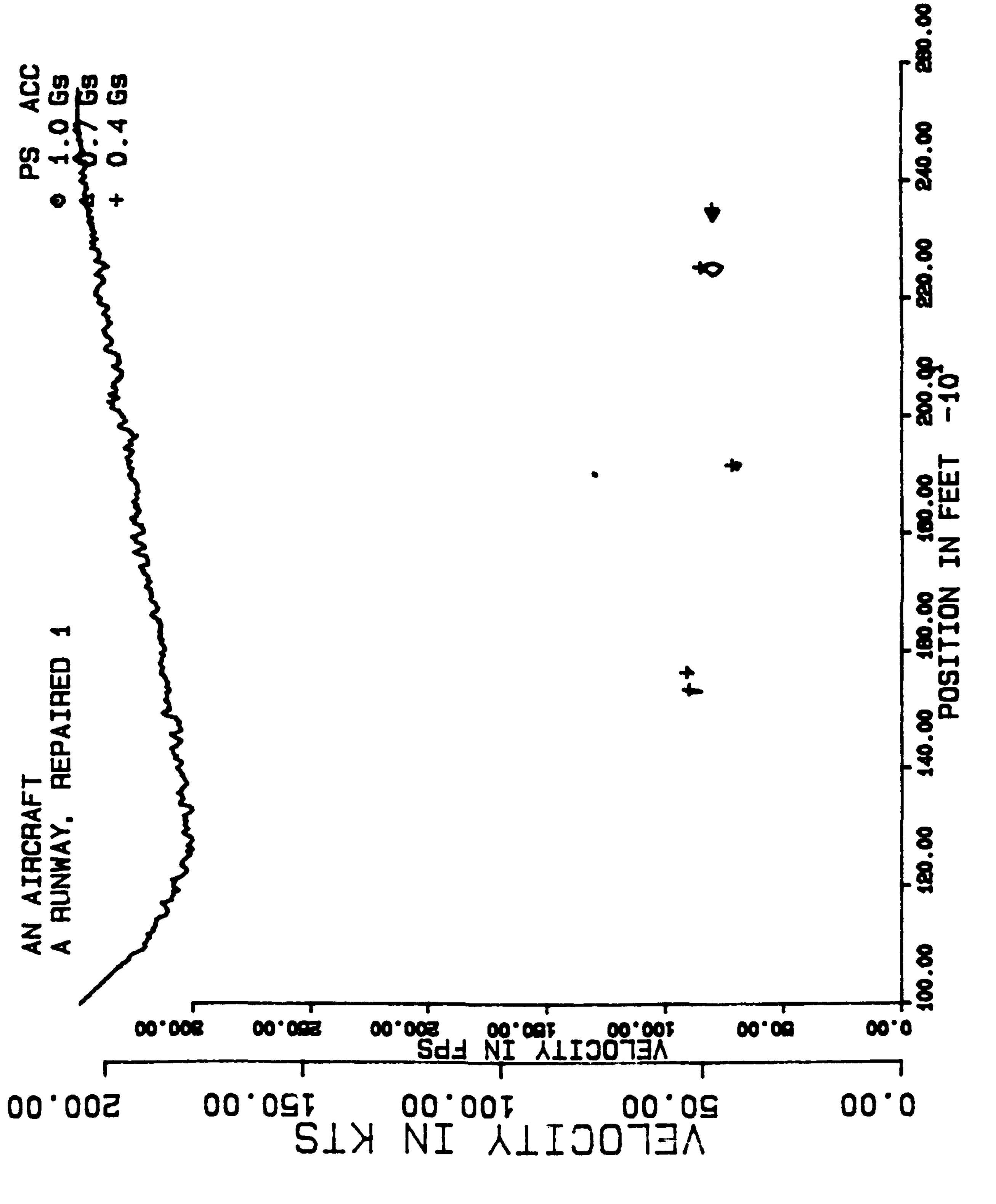

FIGURE VI: PILOT'S STATION RESPONSE TO 1000 TO 1500 FEET

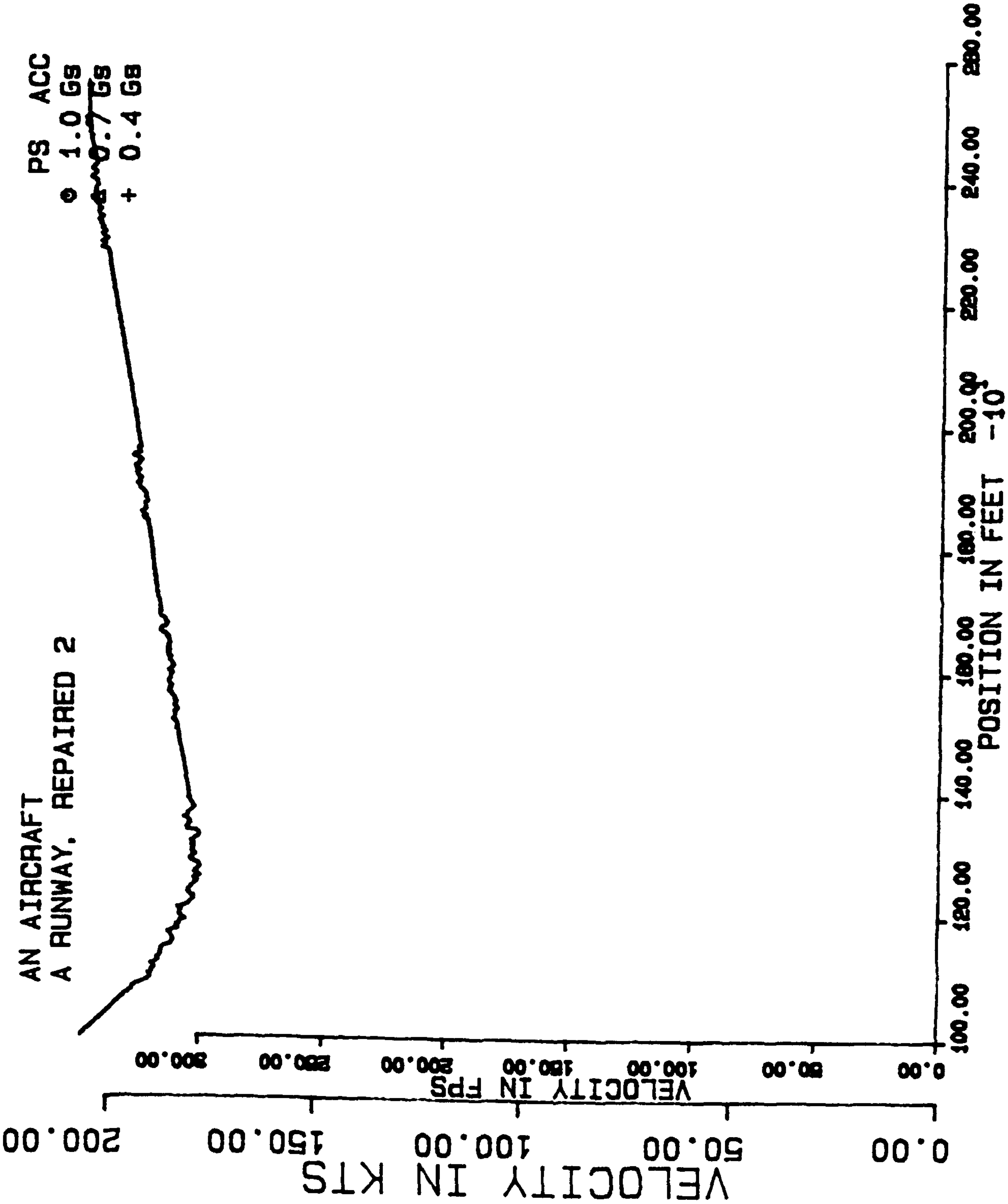

FIGURE VII: PILOT'S STATION RESPONSE TO REPAIRED 1000 TO 1500

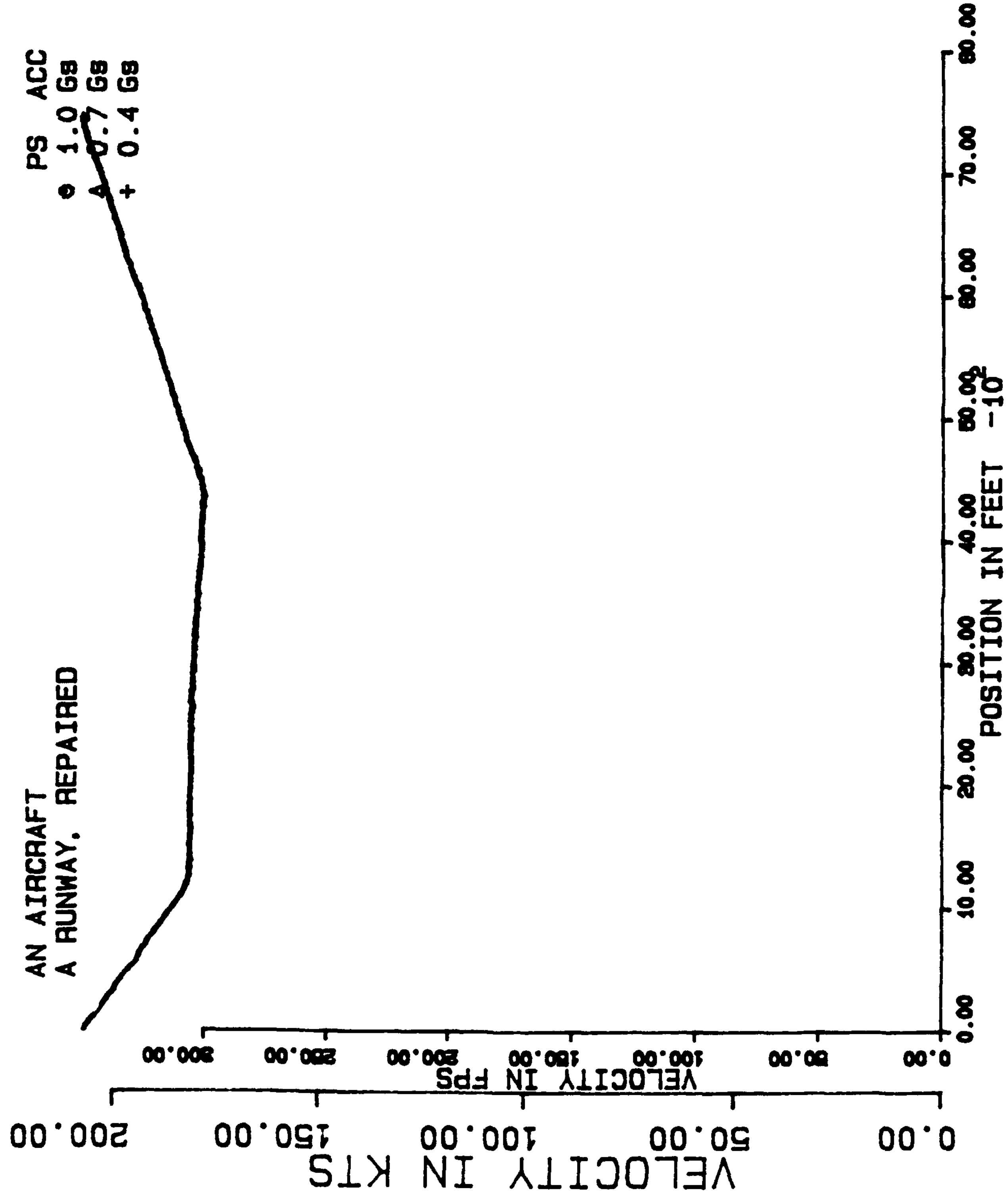

FIGURE VIII: PILOT'S STATION RESPONSE TO REPAIRED RUNWAY

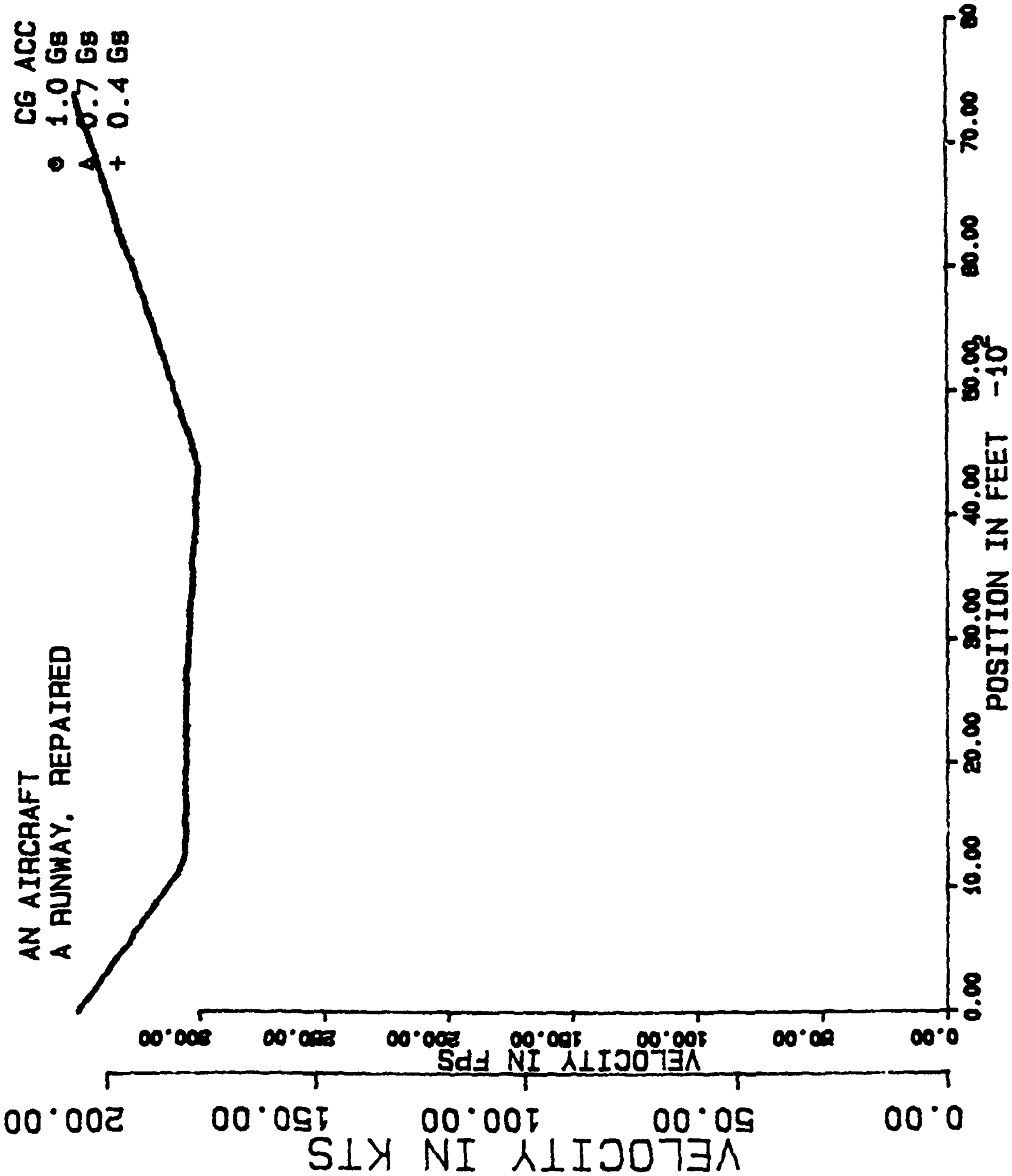

FIGURE IX: CENTER OF GRAVITY RESPONSE TO REPAIRED RUNWAY

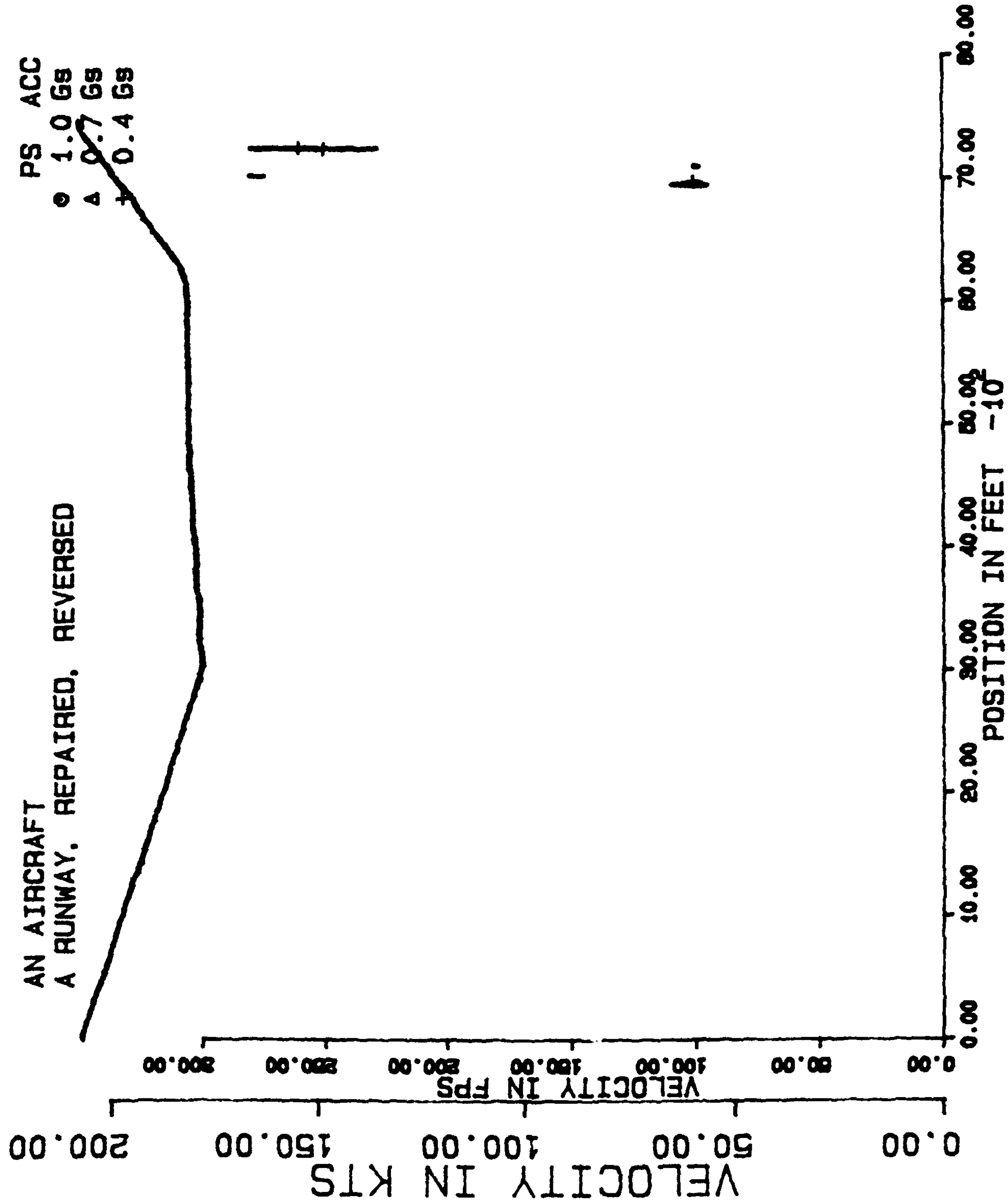

FIGURE X: PS RESPONSE TO REPAIRED REVERSED RUNWAY

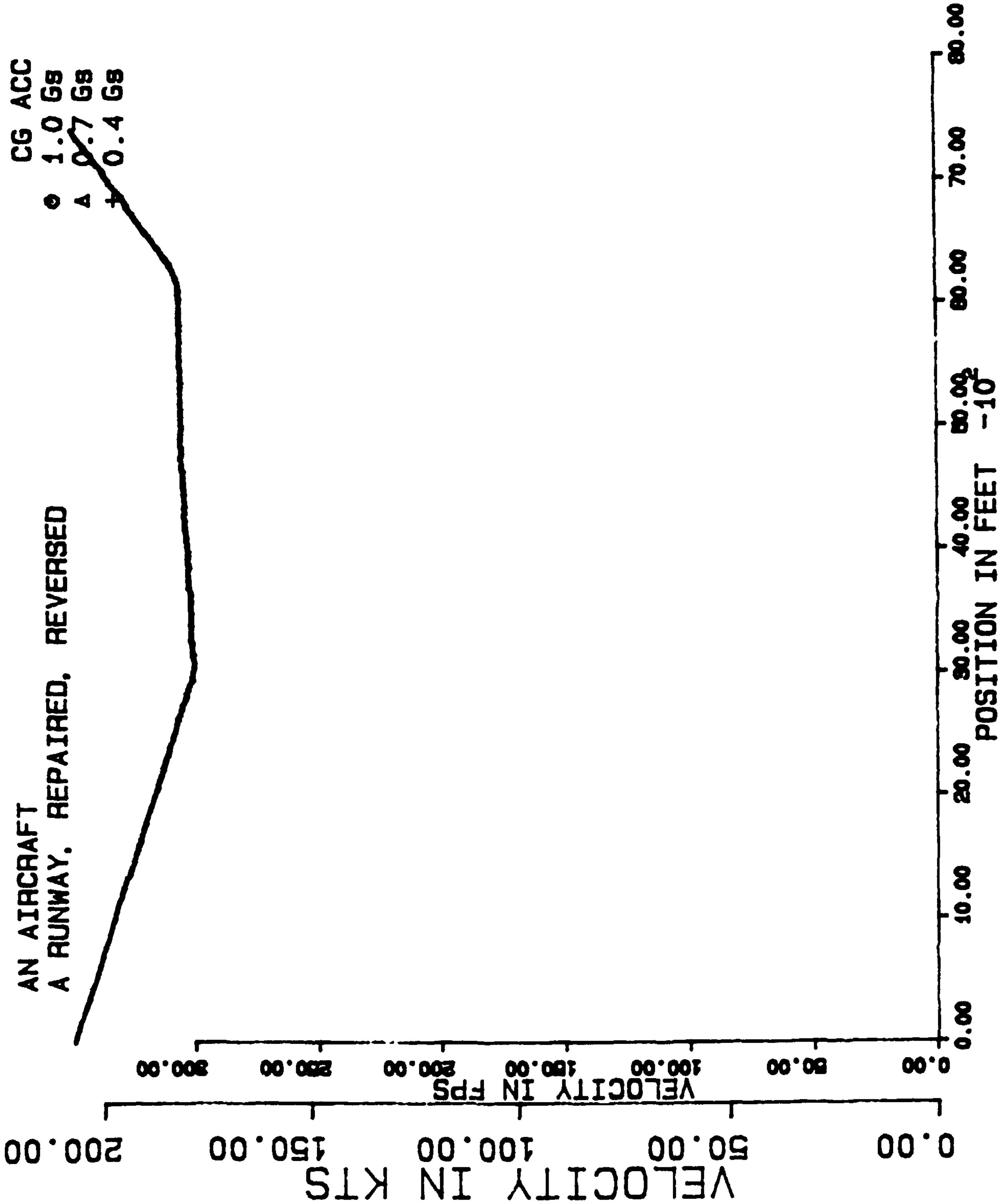

FIGURE XI: CG RESPONSE TO REPAIRED REVERSED RUNWAY

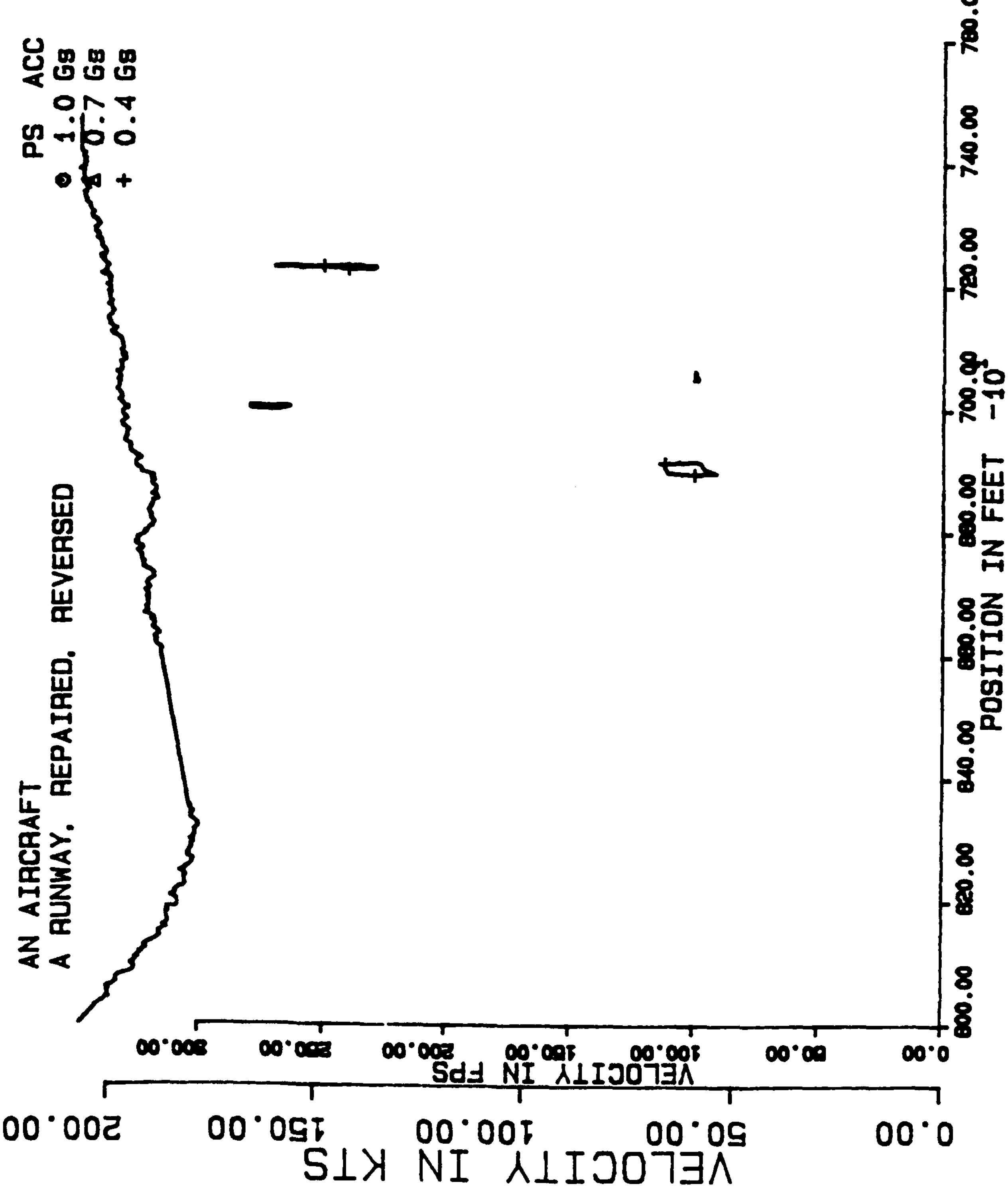

FIGURE XII: PS RESPONSE TO REPAIRED REVERSED 6000 TO 7500 FEET

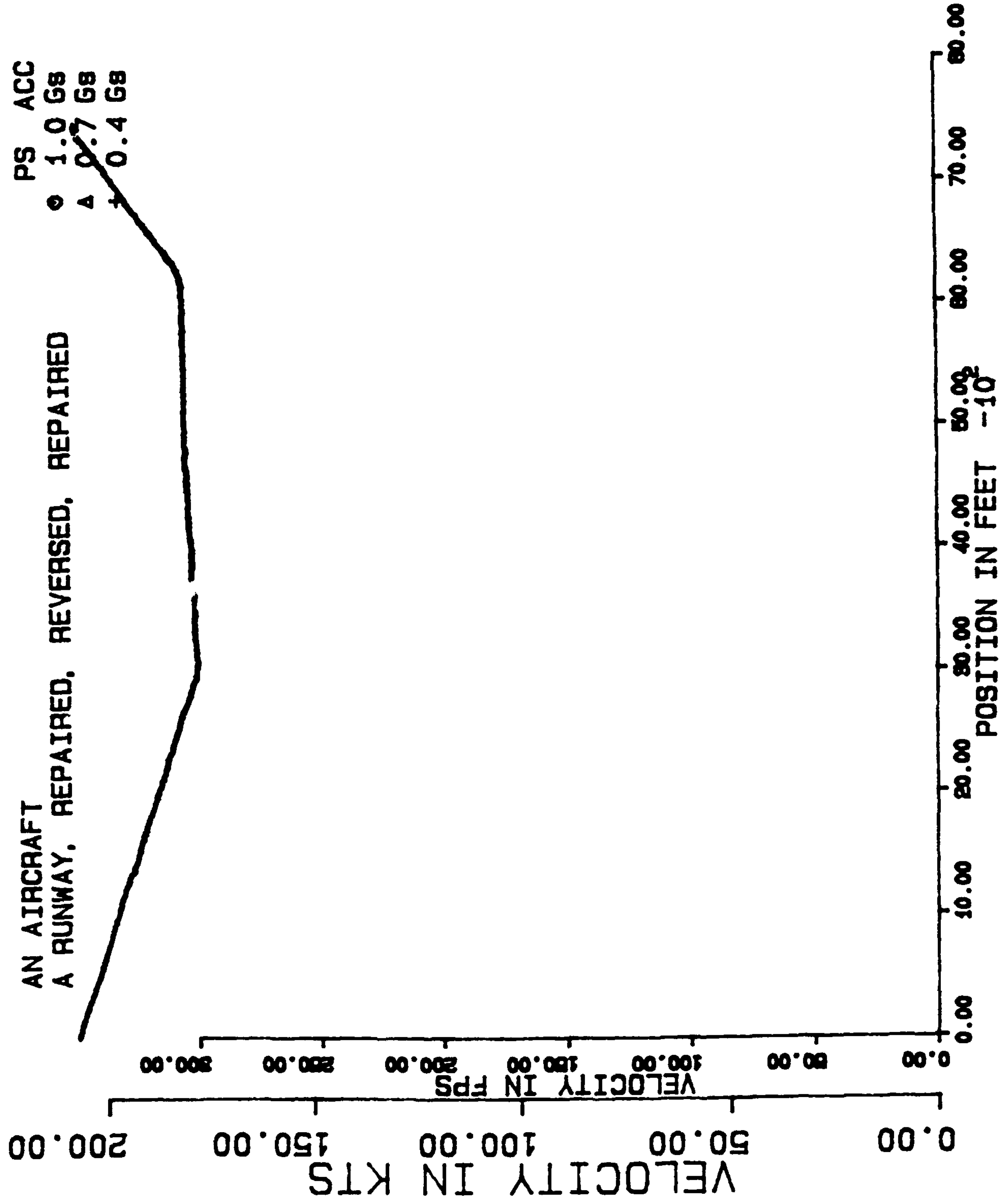

FIGURE XIII: PS RESPONSE TO REPAIRED REVERSED REPAIRED RUNWAY

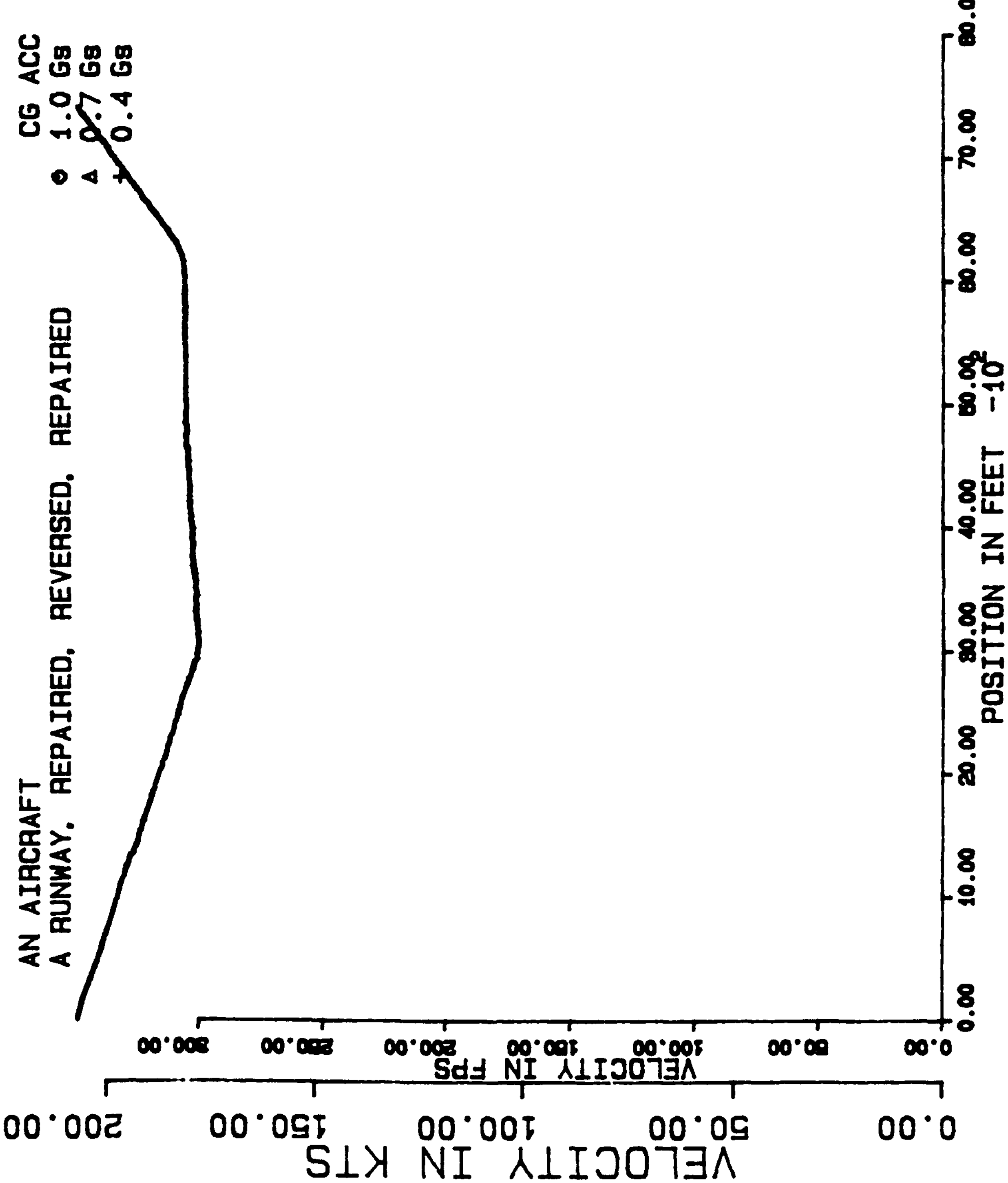

FIGURE XIV: CG RESPONSE TO REPAIRED REVERSED REPAIRED RUNWAY

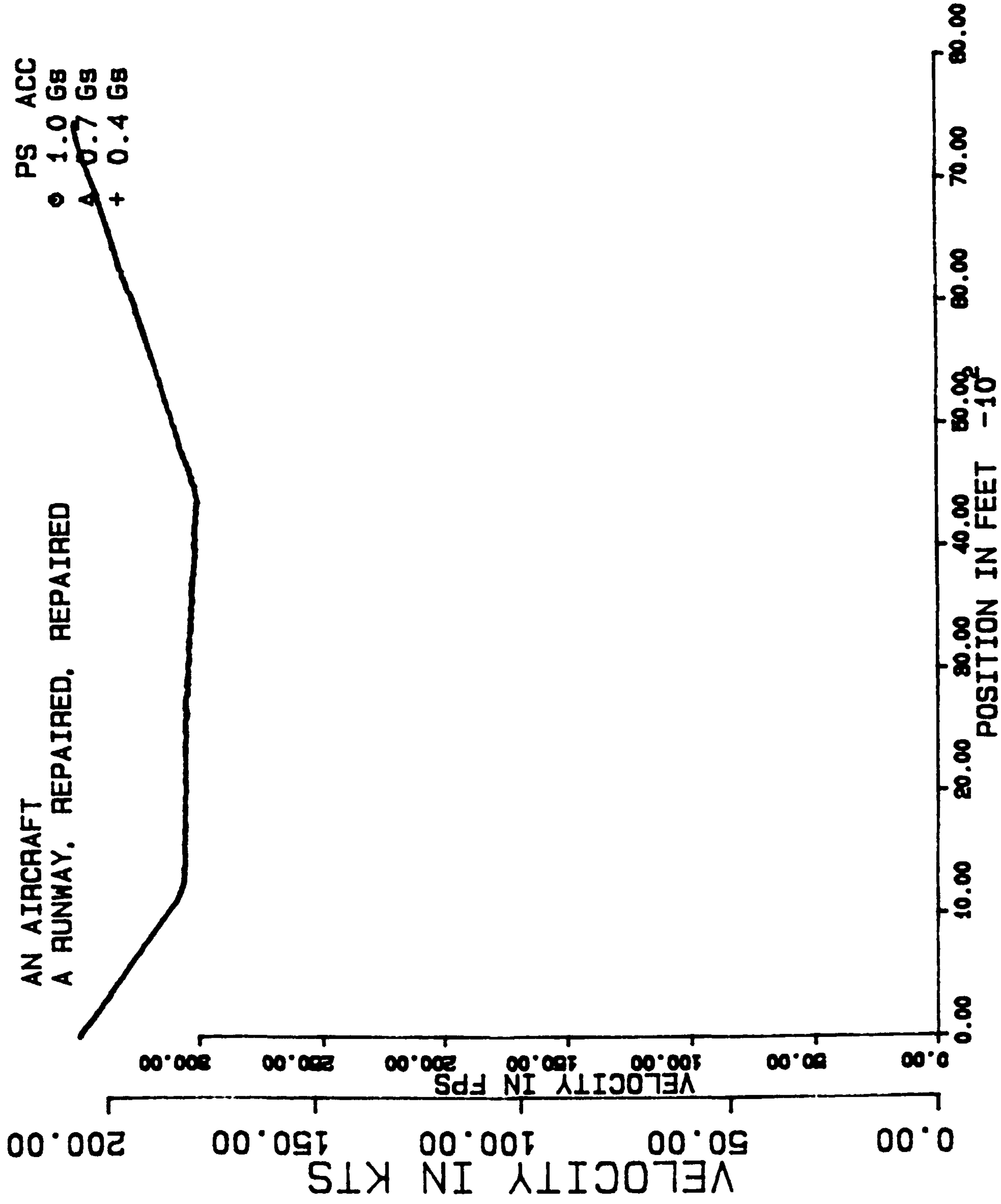

FIGURE XV: PS RESPONSE TO REPAIRED REPAIRED RUNWAY

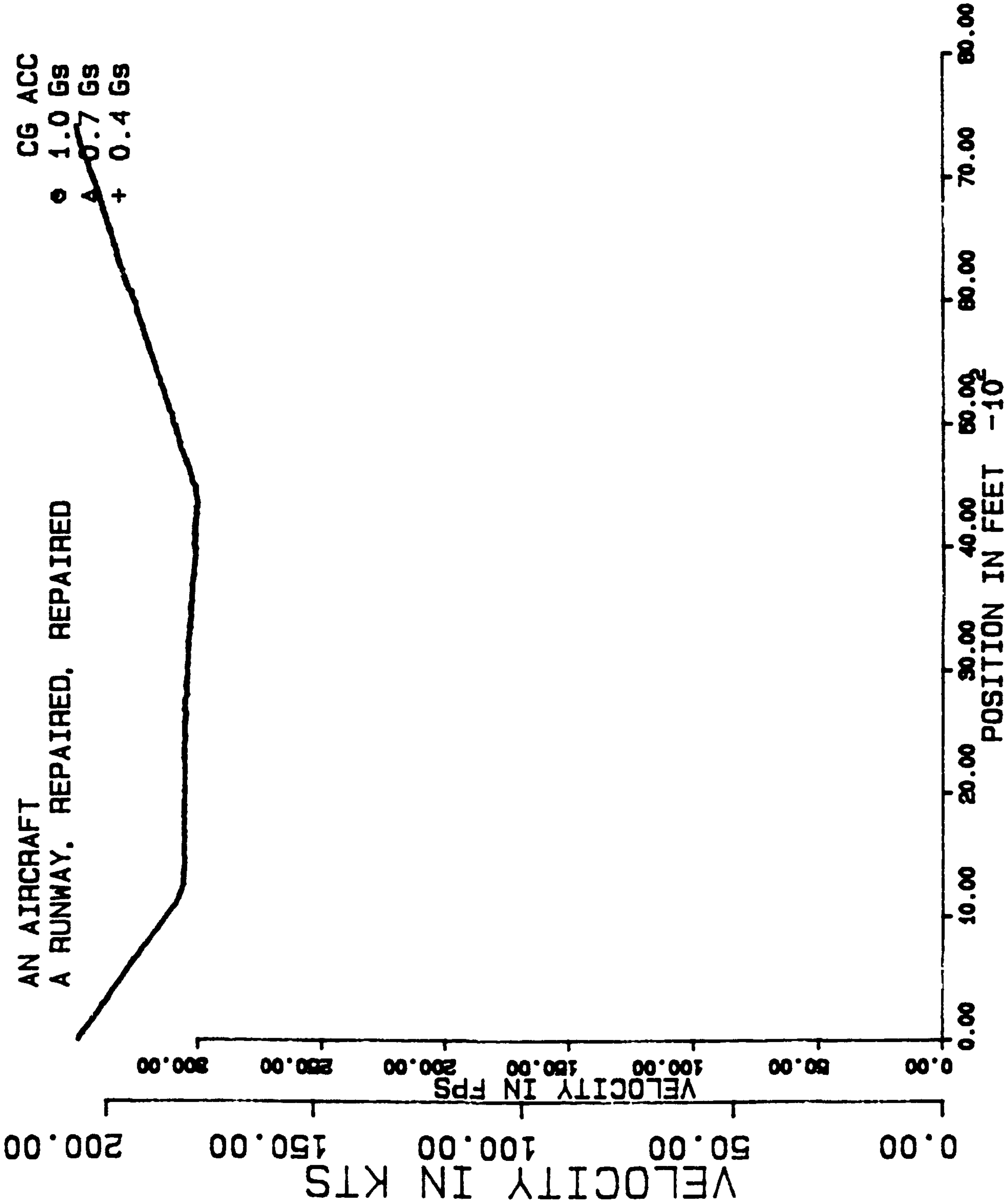

FIGURE XVI: CG RESPONSE TO REPAIRED REPAIRED RUNWAY

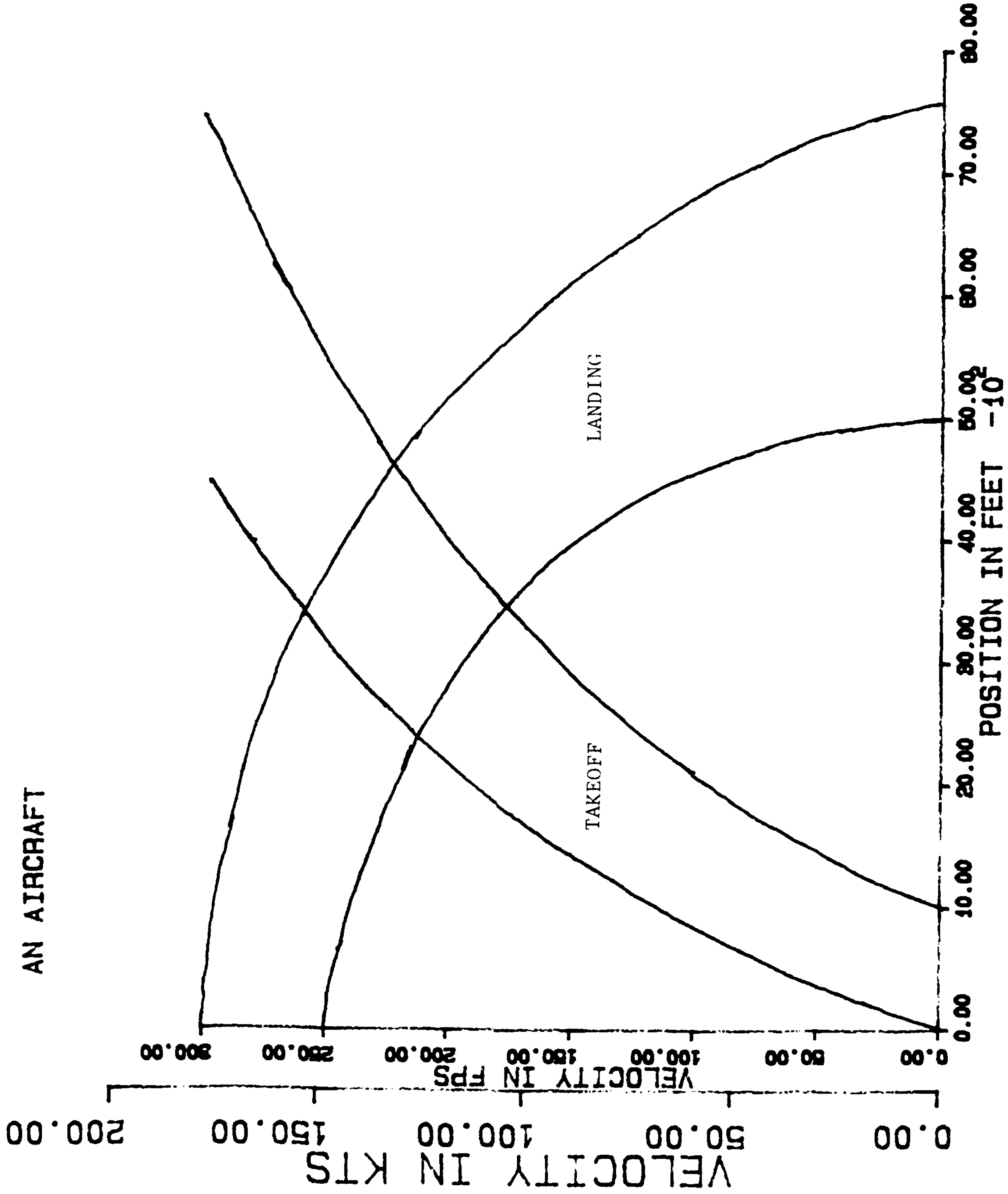

FIGURE XVII: TA[illegible]FF AND LANDING OPERATIONAL ENVELOPES

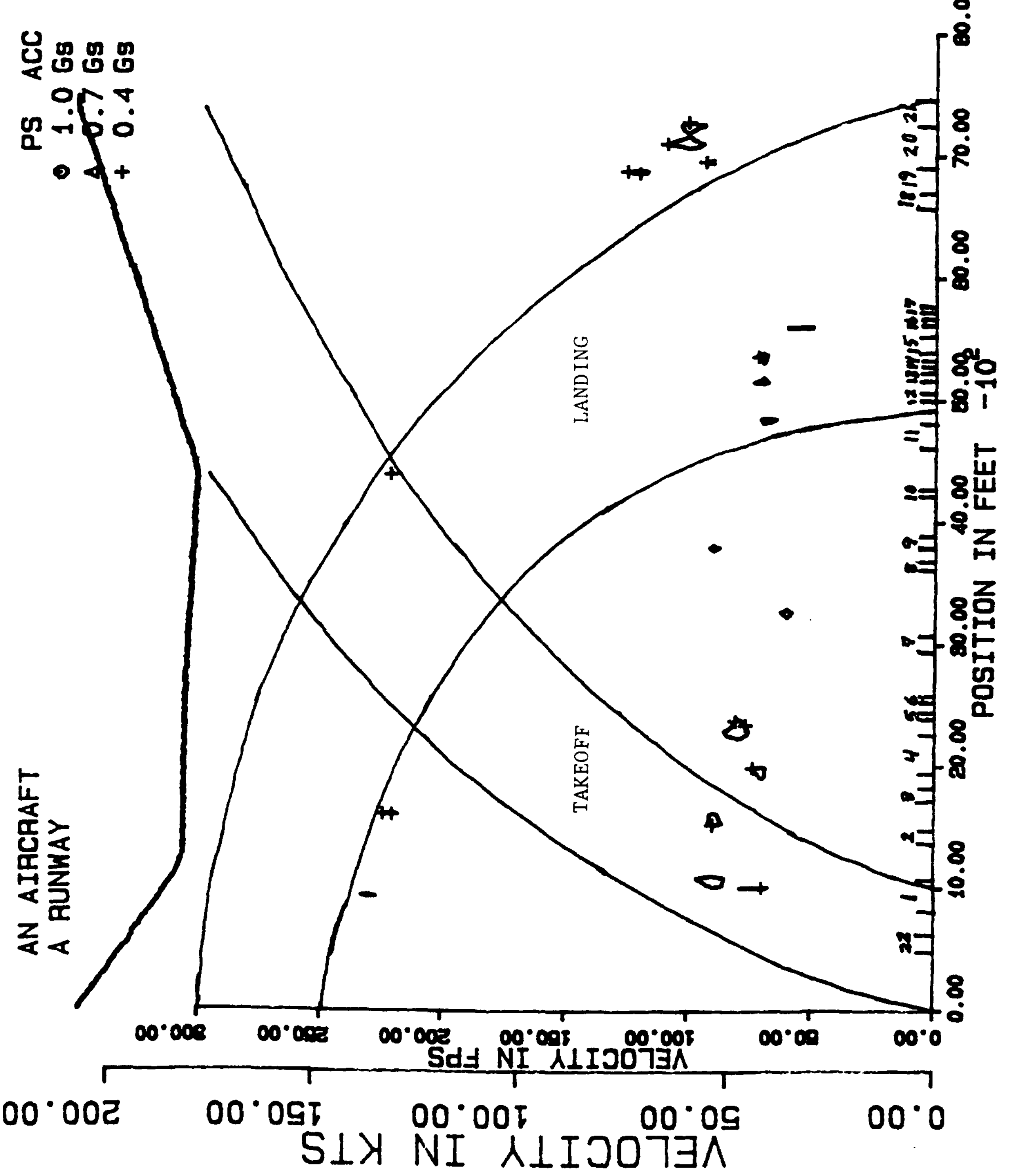

FIGURE XVIII: PS RESPONSE TO UNREPAIRED RUNWAY WITH REPAIR LOCATIONS AND OPERATIONAL ENVELOPES

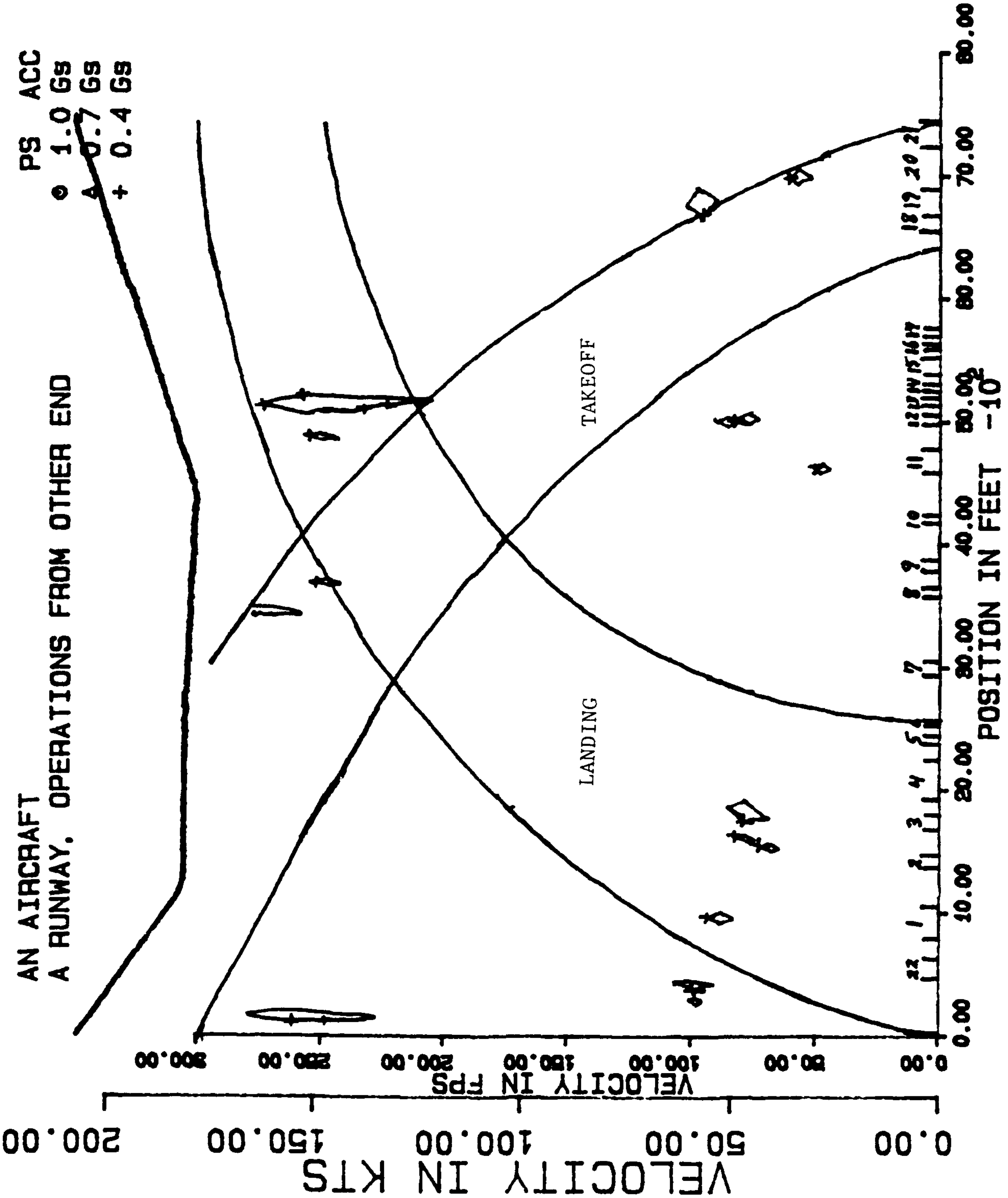

FIGURE XIX: PS RESPONSE TO UNREPAIRED RUNWAY FROM OTHER END WITH REPAIR LOCATIONS AND OPERATIONAL ENVELOPES

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